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Bank Protection on Storage Reservoirs for Municipal Coastal Areas

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Abstract

The shores of the seas and storage reservoirs are in the same property of the state, as its subsoil, forests, water resources. The urgency of coastal protection against the abrasion especially increased in recent decades (in connection with the construction of new ports, coastal cities, energetic and chemical objects, and rapid development of the resort construction). The protection of the municipal coastal areas is more important, safety of human habitation is often dependent on this. Thus, measures against abrasion are no less important than the protection of land from erosion, and storage reservoirs and rivers from pollution. The paper is based on a research of the negative factors associated with abrasion, and selection of bank protection structure type of the storage reservoirs. Selected structure should allow to provide the necessary protection of reservoir's banks from the wave destruction, both urban conglomerate parcels and agricultural, for example on the Kuibyshev reservoir.

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Keywords: municipal hydraulic engineering work; municipal area bank protection; Volga-Kama cascade; reservoir; abrasion; evaporation; gabion retaining wall; coastal municipal development.

1. Introduction

The paper is based on a research of the negative factors associated with abrasion, and selection of bank protection structure type of the storage reservoirs. Selected structure should allow to provide the necessary protection of reservoir's banks from the wave destruction, both urban conglomerate parcels and agricultural, for example on the Kuibyshev reservoir.

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Abrasion is a process of destruction and demolition of the land of the water bodies [1]. This is an urgent global problem for large lakes and reservoirs, which directly reflected on municipal coastal areas' conditions. Waves continuously eroding shores, all the protrusions and irregularities are smoothed out. Underwater wave-cut terrace produced in this way. As the sea penetrates, the width of the terraces increases and the living force of the waves diminishes due to the friction of the surface. If the water bodies level rises relative to the adjacent coast, the destructive work of waves penetrate further inland, and abrasion terrace width increases (sometimes up to 10-20 km) [2].

Abrasion is very strong on reservoirs whose shores geomorphologically young and almost never become mature, equilibrium, because it requires more time than would the reservoir be.

Among the causes of abrasive phenomena identified the following:

- wave conditions of the reservoir;
- ice impact;
- mode of sediment movement;
- decrease of the strength properties of soils [3-7].
- The main consequences of the destruction of the coasts are:
- removing of large areas of agricultural and forest land from the land tenure;
- development of landslide hazard in built up areas [8].

All of the aforementioned facts show the significance of the abrasion problem, both global for country as a whole, and local for municipal authorities.

Volga-Kama cascade is reviewed as example of abrasion influence.

2. State of the problem

Volga-Kama cascade (VKC) cascade of storage reservoirs and water-power plants in the Volga river basin. About 800 reservoirs with a total useful capacity of about 100 cubic kilometers allowing adjusting the 40% average annual flow of the river (254 km³) was built in the basin till 2010s [9]. Among some important problems of the VKC are the following:

bank scraping (abrasion);

flooding;

evaporation from the reservoir basin.

According to the researched sources Kuibyshev reservoir is the most affected by abrasion [10]. The basin of the Kuibyshev reservoir has been allocated with the SAS.Planet free tool [11]. Corresponding boundary was processed in AutoCAD. The reservoir shape was determined by the available data of the bank scraping speed per year (5900 km2). The reservoir shape was obtained, taking into account the increase of the area per year. As a result, the annual increase in reservoir surface area was obtained. It was determined that each year an area of Kuibyshev reservoir increased by 0.035% of its current area.

For 10 years the increase in the surface area of the reservoir will be:

$$5900 \cdot (1 + 0.035/100)10 = 5920.68\,\text{km}^2;\ 5920.68 - 5900 = 20.68\,\text{km}^2$$

That is why we should pay particular attention to the strengthening of reservoir banks.

Flooding is one of the most widespread manifestations of the adverse impacts of water, characterized by a significant spread, duration and scope of caused economic losses. Flooding develops as a complex natural process under the influence of a combination of factors; the main ones are the affluent of groundwater [12, 13]. Flooding area is about 27% of the area of the Volga basin. The third important issue is the evaporation from the reservoir's surface [14]. According to the published data, the estimated average annual loss of water to additional evaporation is also maximized at the Kuibyshev reservoir (3.33 km3 per year) [8, 10].

An annual increase of evaporation from the reservoir basin was calculated, as well as its dependence on direct increase of banks scraping. Surface area of the reservoir at the moment (5900 km2) and its annual increase of bank scraping (2.082 km2), we find that each year the evaporation from the reservoir mirror increases by 0.036%. Evaporation in 10 years will be equal to:

$$3.33 \cdot \left(1 + \frac{0.036}{100}\right) 10 \; = \; 3.342 \; km^3 per \; year$$

Increase of evaporation during this period will be:

$$3.342 - \; 3.33 = 0{,}012 \; km^3 \; per \; year$$

This represents 1.8% of the irrevocable water consumption. Increase of the reservoir area negatively affects its water balance in the long term.

Therefore, analyzing all the negative factors, Kuibyshev reservoir requires urgent action to strengthen the banks of the abrasive action.

3. Database of Kuibyshev reservoir's coastal zoning

In order to visualize and accurately assess the extent of the work, with the help of the portal of the Rosreestr (Federal Service for State Registration, Cadaster and Cartography [15]), which contains detailed maps of cadastral land parcels with their value, the average cost of the bank areas of the Kuibyshev reservoir were found. This portal also contains data about the existence of bank protection, which is reflected in the maps, so parcels of the shore of the reservoir have been identified, where bank protection works were carried out. GIS database around Kuibyshev reservoir basin was made with the SAS.Planet tool. In the environment of ArcGIS [16] data from the Rosreestr portal were digitized. GIS database of Kuibyshev reservoir`s coastal zoning was compiled, with the separation into cost per square meter. In addition, the identification of protected parts was made (Fig. 1, 2).

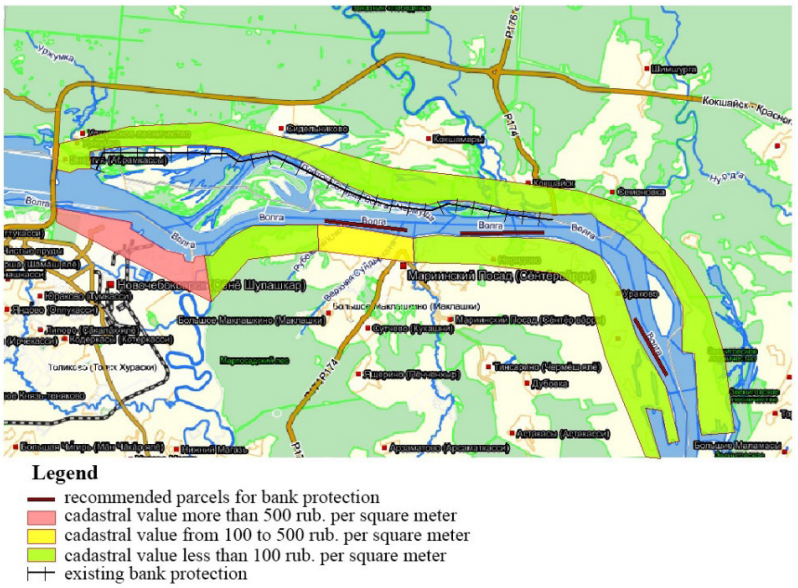

Figure 1. Example of the created Kuibyshev reservoir`s coastal zoning database.

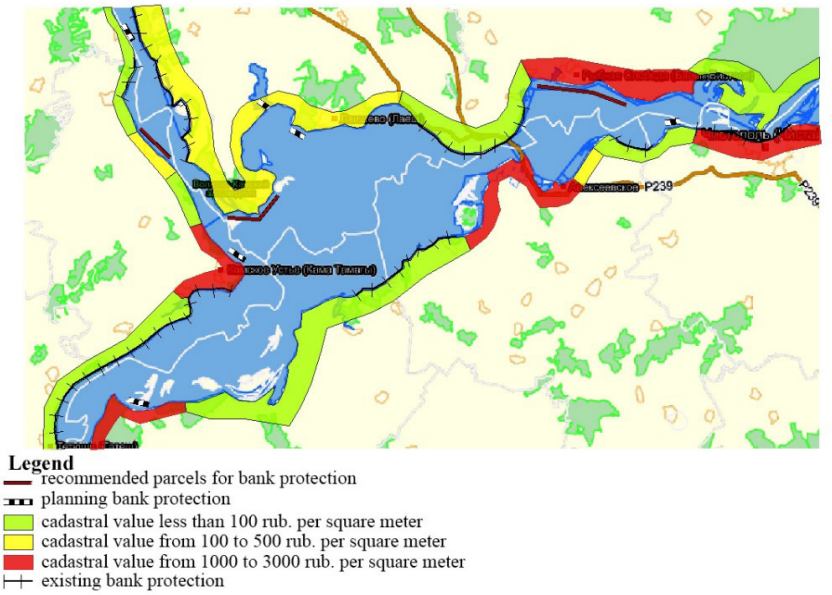

Figure 2. Example of the created Kuibyshev reservoir`s coastal zoning database.

Analyzing the cadastral value database for the presence of the bank protection on the coastal areas, one can see that a large number of areas, with a cost of 500 rubles for the square meter and above, do not currently have a bank protection. Pay respect to processes, occurring on the Kuibyshev reservoir, could be determined, that if no measures will be taken to protect these coastal areas, these lands will be subsequently lost, which leads to:

- large financial losses;
- irretrievable loss of valuable agricultural land;
- danger of disappearance of coastal settlements and the entire infrastructure.

Accordingly, these areas require complex coastal protection [17]. Based on the SKIOVO (schemes of complex use and protection of water objects) data of Volga river basin about long-term activities (construction and reconstruction of buildings) to achieve its target state for the period 2011-2025, the zones, where bank protection works are scheduled, was also marked in the aforementioned created database. Of the nineteenth planned projects currently implemented only seven [11]. According to the created database can be judged that federal target project concerns only a small part of unprotected banks, basically the most expensive. However, the value of the coasts should also be considered from the agricultural point of view, because the loss of important farmlands is irreplaceable [18]. This is shows the importance of cadastral and estate value analysis [19]. That is why problem becomes critical, which leads to the need for measures to protect the reservoir banks.

4. Constructive solution

Were previously considered three options for mounting the coastline:

- Fixing the shore in the form of a retaining wall of Larssen sheet piling. Advantages: coast-protecting structure with the use of the sheet piling has a high overall stability and retains its technological properties of the wave and ice impacts and deformation of the base [20]. Also should be noted that the sheet piling is universal structure and applicable in other areas of the civil engineering [21, 22]. Disadvantages: expensive price of the sheet piling.

- Fixing the shore in the form of a retaining wall and fixing the slope with the gabion structures. Advantages: structure has permeability (acts as a filter for groundwater and external water) [23]. Disadvantages: the complexity of the implementation.
- Fixing the shore in the form of a retaining wall of concrete piling [24]. Advantage: completely rule out the emergence of grassroots shore erosion. Disadvantages: expensive price of the piling.

In this paper for coastal protection from abrasive effects will apply such type of construction as a retaining wall of gabions [25]. Technical and economic indicators are shown in the Table 1.

Table 1. Technical and economic indicators of gabion retaining wall

The average length [m]	1000
The average height [m]	3.0
Type of bank protection	retaining wall of gabions
Constructive elements	• retaining wall of the box gabions • Reno mattress • rubble concrete blocks • mesh reinforcement • crushed stone • sand
Price of the construction [rubles]	96744.31

5. Summary

Reviewed problem of abrasion on the reservoirs turned to be extremely important both globally and locally. The start of its solution should be done directly by the municipal authorities. It is very important to constantly tracking the problem [26]. Organization of gabion retaining wall proposed by authors as a method of abrasion problem solution. The use of gabion structures is one of the highly effective and versatile way to not only strengthen the slopes, but also strengthening, stabilization and protection of the exploited subgrade, regulatory dams, coastal municipal development and other structures [27-29]. Relatively high cost and complexity of construction can be named among the shortcomings. Gabion structures worked well in the arrangement of bank protection of Saratov reservoir. Accepted shore protection structure provides coast stability from erosion, wave action and ice loads at varying levels of Kuibyshev reservoir. Also gabion structures well applicable in situations, when shores and bottom of the reservoir consist of weak soils [30, 31]. Especially, it is a pure material from an environmental point of view [32].

The constructional solutions allow:

- protect shorelines from erosion and wave action;
- restore and improve the natural landscape;
- not to cause damage to the environment.

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